Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans
National Capital Region
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Science Response 2017/040

SCREENING OF PACIFIC FISHERY REGULATIONS (PFR) SCHEDULE VIII SPECIES FOR RISK OF INVASIVENESS

Context

The *Pacific Fishery Regulations* (PFR) Schedule VIII contains a list of aquatic taxa that are prohibited from live import into British Columbia; however, the list is large, out of date, and taxonomically confounded. For example, in all but one case, genera, rather than species, are listed in the PFR Schedule VIII (Table A1) such that when these genera are expanded to identify species, half (49.7%) have been taxonomically reclassified into other genera since the inception of the list. Further, it is unknown if all species of each genus were intended to be in the PFR Schedule VIII or if they were even included due to potential invasiveness. As there is a desire to ensure consistency between relevant aquatic taxa listed in the PFR Schedule VIII and those listed (or to be listed) in the *Federal Aquatic Invasive Species* (AIS) *Regulations*, a risk assessment process is needed to inform potential future amendments to the Federal AIS Regulations. To ensure that the risk results can be compared effectively across all taxa contained in the PFR Schedule VIII, facilitating any future regulatory amendments, species on the list are being assessed using a single screening-level risk assessment tool, the Canadian Marine Invasive Screening Tool (CMIST). CMIST was previously developed and tested on marine invertebrates (DFO 2015; DFO 2016; Drolet et.al. 2016) and provides a mechanism to rank assessed species based on their biological invasion risk and differentiates likelihood of invasion and potential impacts.

Fisheries and Oceans Canada's (DFO) Ecosystems and Fisheries Management (EFM) sector has requested science advice to: 1) evaluate the suitability of CMIST for use on all aquatic taxa represented in the PFR Schedule VIII, and 2) in the context of the above analysis, evaluate the aquatic taxa listed in the PFR Schedule VIII for risk of invasiveness in British Columbia. The PFR Schedule VIII contains 1160 fish species belonging to 48 genera and 375 invertebrate species belonging to 6 genera. More specifically, the fishes are primarily freshwater species (1048) rather than marine/brackish ones (112) and the invertebrates are marine gastropod molluscs and decapod crustaceans. CMIST was developed and tested on marine invertebrates only; however, the Montreal Rapid Assessment Tool (RAT), a predecessor to CMIST, was determined to be applicable to freshwater fishes in trade (Mandrak et al. 2014). To ensure CMIST would be suitable for all taxa listed in the PFR Schedule VIII, a subset of these species (including taxonomically reclassified ones) was used to evaluate the suitability of CMIST. Further, since the PFR Schedule VIII includes more than 1500 species, the prioritization process used when applying CMIST to the PFR Schedule VIII will be outlined here, including the supporting rationale.

The purpose of this Canadian Science Advice Secretariat (CSAS) Science Response (SR) is to review the results for a subset of species of each aquatic taxon listed in the PFR Schedule VIII that were evaluated using CMIST (i.e., fishes, gastropods and crustaceans), and determine the suitability of using CMIST for these aquatic taxa. The advice arising from this SR will validate CMIST applicability to additional taxa, specifically those listed in the PFR Schedule VIII. The assessment and advice provided may be used to provide guidance for similar assessments for other taxa/lists.

This Science Response Report results from the Science Response Process of February 20-21, 2017 on the Screening of Pacific Fishery Regulations (PFR) Schedule VIII Species for Risk of Invasiveness.

Background

The province of British Columbia has asked that additional species be added to the prohibited species schedule under the AIS Regulations in the *Fisheries Act*. The Pacific Fishery Regulations (PFR) Schedule VIII contains a list of aquatic taxa that are prohibited from live import into British Columbia but the rationale for the genesis of the PFR Schedule VIII is unclear, taxonomically confounded, and potentially was not consulted on. Thus, it was determined an analysis was needed to identify potential AIS risks associated with the species listed in the PRF Schedule VIII and a screening-level risk assessment was undertaken starting in April 2014 to identify potential AIS for British Columbia that could be considered for listing in the AIS Regulations in the *Fisheries Act*.

Analysis and Response

Identification of Species Listed in the PFR Schedule VIII

Since both the Federal AIS Regulations in the *Fisheries Act* and the Provincial Controlled Alien Species (CAS) Regulation in the *British Columbia Wildlife Act* apply to species, this was the taxonomic unit determined most suitable for analysis. For fishes, FishBase was used to generate the list of species the PFR Schedule VIII could apply to that included both currently recognized taxonomic names and those where taxonomic revisions had occurred since the inception of the PFR Schedule VIII. Similarly, for invertebrates the species list was generated using nomenclature, both current and revised, from WoRMS. This resulted in 1160 fish species and 375 invertebrate species being identified for the PFR Schedule VIII.

For this SR, the subset of species used to evaluate the applicability of CMIST included 60 freshwater fish species, 30 marine/brackish fish species, and 30 invertebrate species that included different climate matches if available (see below) and represented taxonomically different groups. Detailed-level risk assessments were available for three species in this subset, and an additional eight PFR Schedule VIII fish species were added to the subset for which detailed-level risk assessments were available: four assessed for British Columbia (Bradford et al. 2008a; Bradford et al. 2008b; Tovey et al. 2008) and four additional Asian Carp species assessed for Canada (Mandrak and Cudmore 2004). Further, to ensure a representative mix of species we included species that are prohibited/restricted or on AIS watch lists (i.e., "hit list" below) and those that were not. Similarly, to ensure taxonomic reclassifications were considered in the analyses, for both fishes and invertebrates, we included both species with valid taxonomic names that match the PFR Schedule VIII and species that are now recognized by a different nomenclature but that had nomenclature that previously matched the PFR Schedule VIII. Finally, species that obtained a mixture of lower, moderate, and higher scores with CMIST were drawn for evaluation purposes. Since the PFR regulations apply specifically to British Columbia this was the assessment area, including freshwater, marine and estuarine ecosystems in accordance with the species being assessed. In addition, some PFR Schedule VIII species are native to parts of the assessment area but could be invasive in other parts. For these species the risk was determined based on potential non-native range/habitats in British Columbia.

Climate Match

One of the strongest filters in the invasion process is climate, as without some degree of overlap in species tolerances and environmental conditions an invasion is likely to fail (e.g., Gollash 2002, Mandrak et al. 2014). Thus, many risk assessments often rely on some measure of climate match as an initial filter. With the exception of the sub-tropical/tropical fish species scored with CMIST for tool validation, applying this same principle to PFR Schedule VIII species would dictate that species that have a poor climate match would not be retained for assessment while those with a climate match would be assessed with the screening-level risk assessment tool CMIST. This does not mean that species with poor climate match pose no risk. Rather, the lack of climate match suggests that the invasion likelihood is lower due to reduced probabilities of survival and reproduction (needed for establishment) than species with a climate match and so overall, the relative risk is lower. Further, species without a climate match are less likely to reach population abundances that are truly invasive such that there is also a lower probability of significant impacts, which also would result in a lower overall relative risk.

A precautionary approach was used to determine climate match for PFR Schedule VIII species. For fishes, if the species was identified as temperate in FishBase or it was identified by another climate label such as a sub-tropical or tropical but could survive/reproduce in waters ≤12°C or its distribution included a latitude ≥37°N or S then it was considered a species that could survive and potentially establish in British Columbia and was retained for assessment with CMIST. However, if it was identified as a sub-tropical or tropical species in FishBase or it required warmer waters for survival/reproduction (>12°C) and its distribution was limited to latitudes <37°N or S it was considered a species with poor climate match to British Columbia and would not be retained for assessment with CMIST. For marine invertebrates there was no single source like FishBase to determine climate match. Thus, we used a variety of online resources (primarily WoRMS, OBIS, GBIF, and E-Fauna) and literature surveys to classify species based on latitudinal thresholds that correspond to climate zones: tropical (<23.5°N or S), subtropical (23.5-35°N or S), temperate (35-66.5°N or S), and polar (>66.5°N or S). If a species' range (native or invaded) included temperate latitudes it was considered a species with climate match to British Columbia and was retained for assessment with CMIST. If its range did not include a match to temperate latitudes it was not assessed with CMIST.

As noted above, non-temperate species would not normally be retained for assessment with CMIST, but for the purposes of evaluating the suitability of CMIST in this SR we identified a subset of freshwater fish species listed in the PFR Schedule VIII both with a climate match to British Columbia (30 species) and without a climate match (30 species). The additional species for which detailed-level risk assessments were available (8 species) all had a climate match to the assessment area. For marine invertebrates (15 gastropods and 15 crustaceans) and marine fishes, the 30 species of each taxa included in this assessment each had a climate match to British Columbia; PFR Schedule VIII invertebrates and marine fishes without a climate match to British Columbia were not assessed in this SR. However, the CMIST tool was developed and tested for marine invertebrates so its application to these taxa has already been confirmed (DFO 2015; Drolet et al. 2016).

CMIST Application to PFR Schedule VIII Species

The potential risk of invasiveness of PFR Schedule VIII species was determined using the CMIST screening-level risk assessment tool. CMIST was developed based on the different steps in the invasion process (Drolet et al. 2016) and explicitly distinguishes the two risk components: 'Likelihood of Invasion' and 'Impact of Invasion' (Kumschick and Richardson

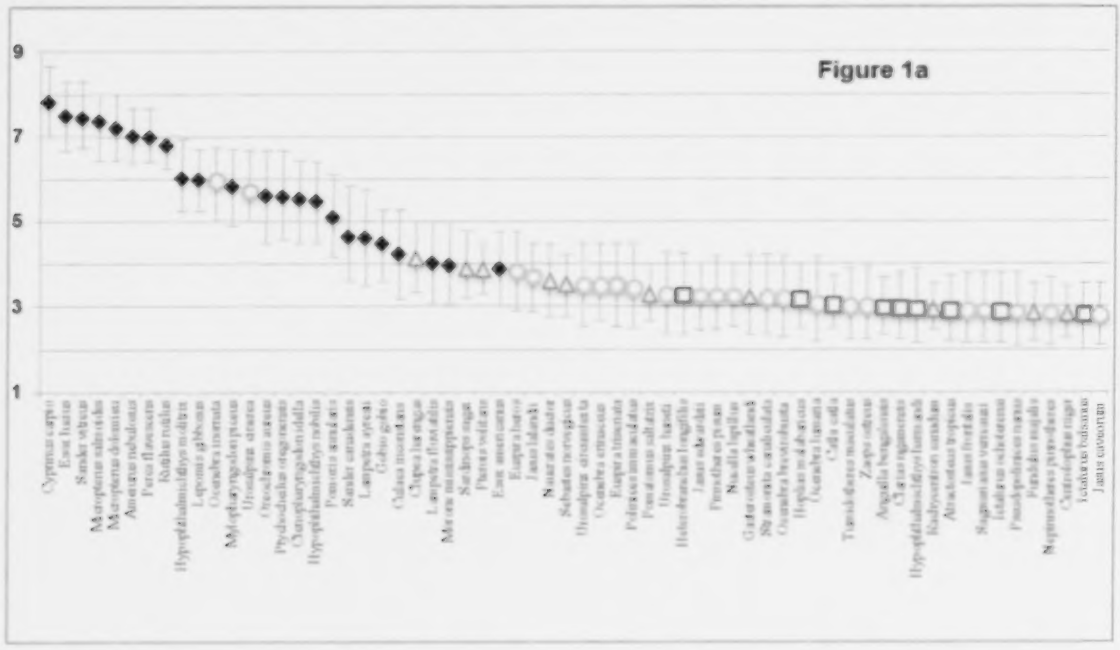
2013). Further, CMIST was developed based on input at a previous DFO CSAS process where different risk assessment frameworks were reviewed (DFO 2012) and is consistent with the Montreal RAT that was applied successfully to freshwater fishes in trade (Mandrak et al. 2014). Also, the CMIST guidance document aims to reduce inter-assessor variability – something that was not available for the Montreal RAT when applied to freshwater fishes in trade (Mandrak et al. 2014). There are 17 CMIST questions and each question is scored on a scale between 1 and 3 ('Low' = 1 to 'High' = 3). A mean score is calculated for the Likelihood of Invasion (i.e., questions 1–8) and Impact of Invasion (i.e. questions 9–17) and these scores are then multiplied to obtain a risk score ranging from 1 to 9. In addition to answering each risk question, assessors also assign a qualitative uncertainty score ('Very uncertain' = 1 to 'Very certain' = 3) for each question. Each question's answer (score) and associated uncertainty ranking are used in a Monte Carlo randomization procedure to generate an adjusted risk score that includes uncertainty (Drolet et al. 2016) and is consistent with previous DFO CSAS advice (DFO 2015).

For the 128 PFR Schedule VIII species assessed here, CMIST scores ranged from approximately 1.5 (lower risk) to 7.8 (higher risk) (Figure 1; Table A2). Thus, although specific risk thresholds have not been identified for CMIST, the tool was able to successfully differentiate (and rank) PFR Schedule VIII species based on relative invasion risk independent of taxa. Further, all sub-tropical/tropical freshwater fish species that had a poor climate match to British Columbia had CMIST risk scores ≤3.25 at least in part due to lower likelihood of invasion (Figure 2). All but two marine invertebrates (two oyster drills) had CMIST risk scores ≤3.82, similar to the marine fish species evaluated (≤4.12). The temperate freshwater fishes had CMIST scores that ranged between approximately 1.75 and 8 showing CMIST was able to differentiate invasion risk among species with a climate match to British Columbia. Collectively these results suggest that CMIST is suitable for application to all PFR Schedule VIII taxa.

Following the approach used in DFO (2015) we plotted each of the PFR Schedule VIII species assessed for this SR using adjusted Likelihood of Invasion and adjusted Impact of Invasion scores (Figure 2). Sub-tropical/tropical freshwater fish species clustered to the lower left side of this graph confirming that CMIST identified species with poor climate match as lower risk due to inherently lower likelihood of invasion and potential impacts. The invertebrate species assessed here largely clustered to the middle left side of the graph due to lower-moderate likelihood of invasion and lower potential impacts with the exception of the two oyster drills that had higher scores for impact of invasion (known predators of shellfish). CMIST includes a question about occurrence in the assessment area such that species already established automatically score higher for this question. Although this might result in a small difference in the overall risk score between species already present and those not present/reported this alone is unlikely to result in substantial differences among species assessed. The marine fish species assessed here generally clustered to the left side of the graph indicating lower potential impacts, with a few having higher likelihood of invasion scores, possibly owing to good environmental/habitat matches. The temperate freshwater fish species covered a broad range of likelihood of invasion and impact of invasion with some species scoring relatively low for both, others scoring relatively high for both and a mix in between (Figure 2). Consistent with DFO (2015), higher risk species were identified as those occupying the upper right hand corner of this plot which included well-known AIS such as Common Carp, Largemouth Bass, Smallmouth Bass, Walleye, Northern Pike, Brown Bullhead, Roach, and three Asian Carps. In fact, Largemouth Bass and Smallmouth Bass were identified has high risk invaders in British Columbia in previous detailed-level risk assessments (Tovey et al. 2008) as were Northern Pike, Walleye, and Pumpkinseed (Bradford et al. 2008a) and Yellow Perch (Bradford et al. 2008b). Four species of Asian Carp (Grass Carp, Bighead Carp, Silver Carp, and Black Carp) were identified as high risk invaders

to Canada (Mandrak and Cudmore 2004) and three of these were identified here as higher risk species in British Columbia based on CMIST scores (Figures 1 and 2). A fifth Asian carp species, Largescale Silver Carp, was identified as a moderate risk to Canada (Mandrak and Cudmore 2004) and scored lower with CMIST here (Figure 1). These results collectively support the applicability of CMIST to all PFR Schedule VIII taxa.

Interestingly, Blue Tilapia (*O. aureus*) is a temperate species whose nomenclature has changed since the PFR Schedule VIII was developed, was not on any of our "hit lists" (Table 1), and scored relatively high with CMIST. This species is a good example highlighting the need to ensure all temperate PFR Schedule VIII species are assessed as other prioritization filters might have excluded this species for British Columbia.



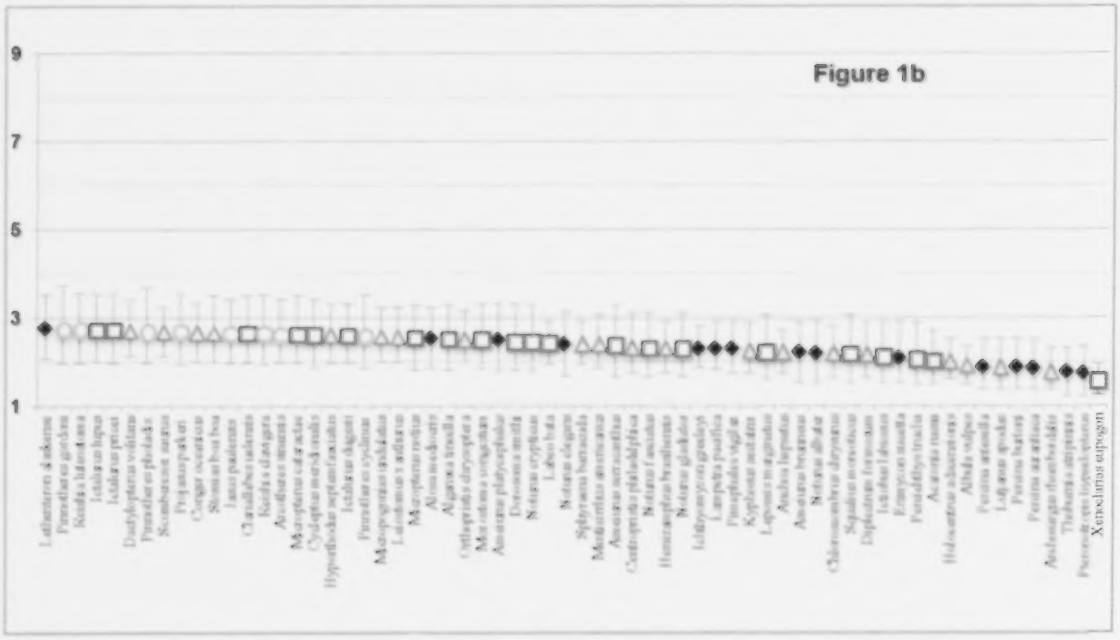


Figure 1: CMIST Scores (adjusted) with confidence limits for 128 PFR Schedule VIII species (38 temperate freshwater fish (filled diamond), 30 sub-tropical/tropical freshwater fish (open square), 30 temperate marine invertebrates (open circle), 30 temperate marine fish (filled triangle)).

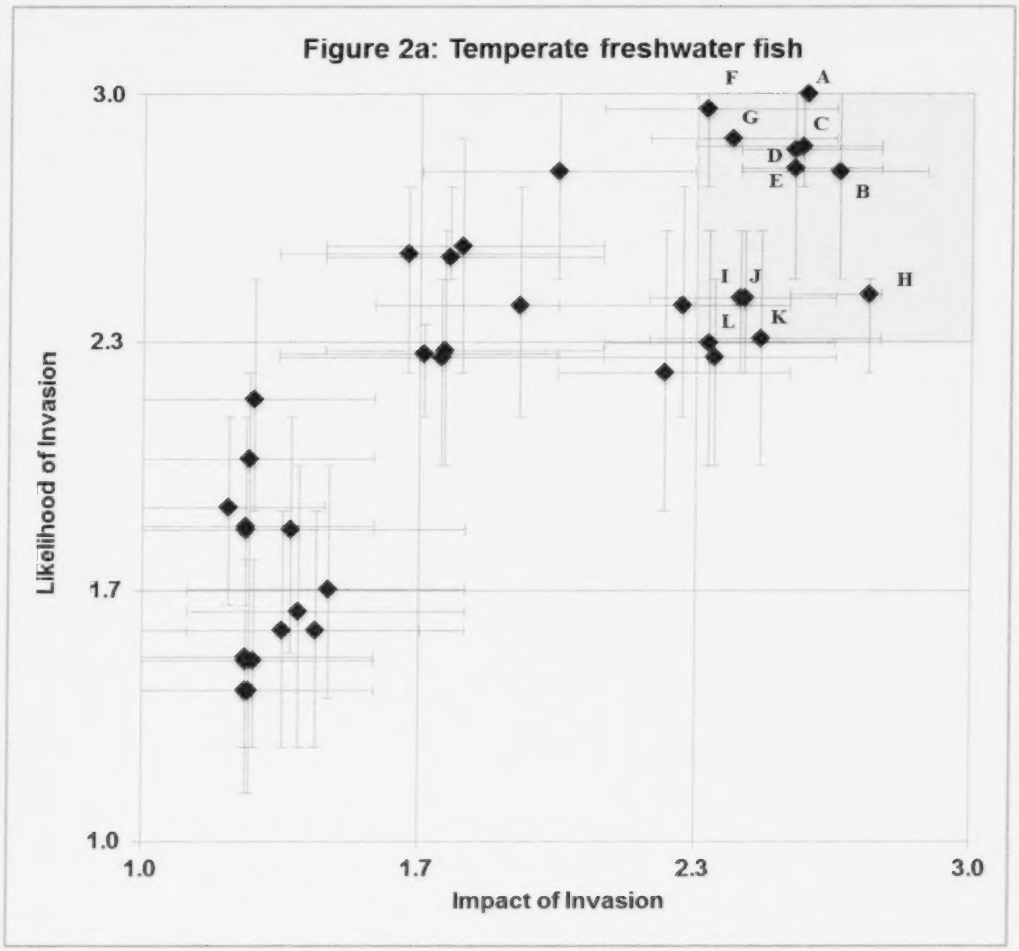


Figure 2 (A): CMIST Scores (adjusted) for 38 temperate freshwater fish from the subset list of 128 PFR Schedule VIII species. Scores are decomposed to Likelihood of Invasion and Impact of Invasion, and displayed in a heat matrix to identify higher risk species following DFO (2015). Higher risk species are in the upper right shaded corner. A=*Cyprinus carpio*, B=*Esox lucius*, C=*Sander vitreus*, D=*Micropterus salmoides*, E=*Micropterus dolomieu*, F=*Ameiurus nebulosus*, G=*Perca flavescens*, H=*Rutilus rutilus*, I=*Hypophthalmichthys molitrix*, J=*Lepomis gibbosus*, K=*Mylopharyngodon piceus*, L=*Ctenopharyngodon idella*

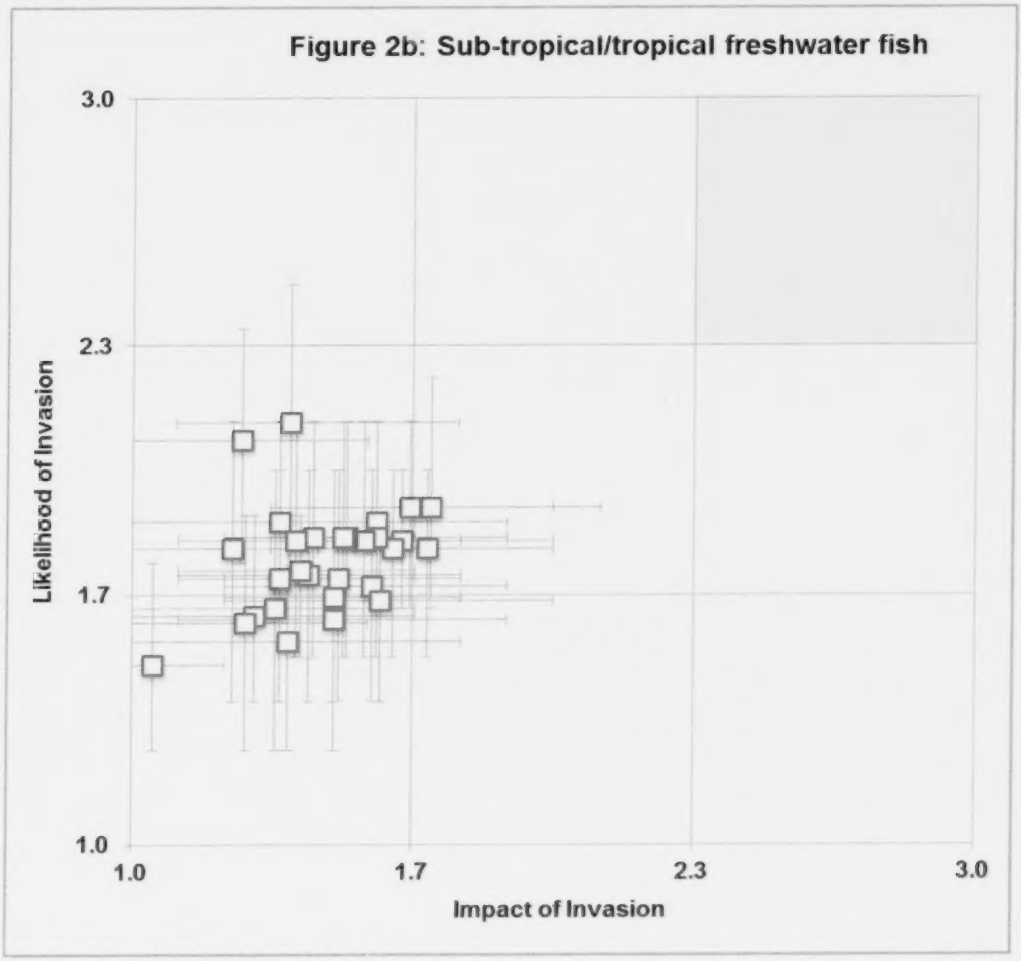


Figure 2 (B): CMIST Scores (adjusted) for 30 sub-tropical/tropical freshwater fish from the subset list of 128 PFR Schedule VIII species. Scores are decomposed to Likelihood of Invasion and Impact of Invasion, and displayed in a heat matrix to identify higher risk species following DFO (2015). Higher risk species are in the upper right shaded corner.

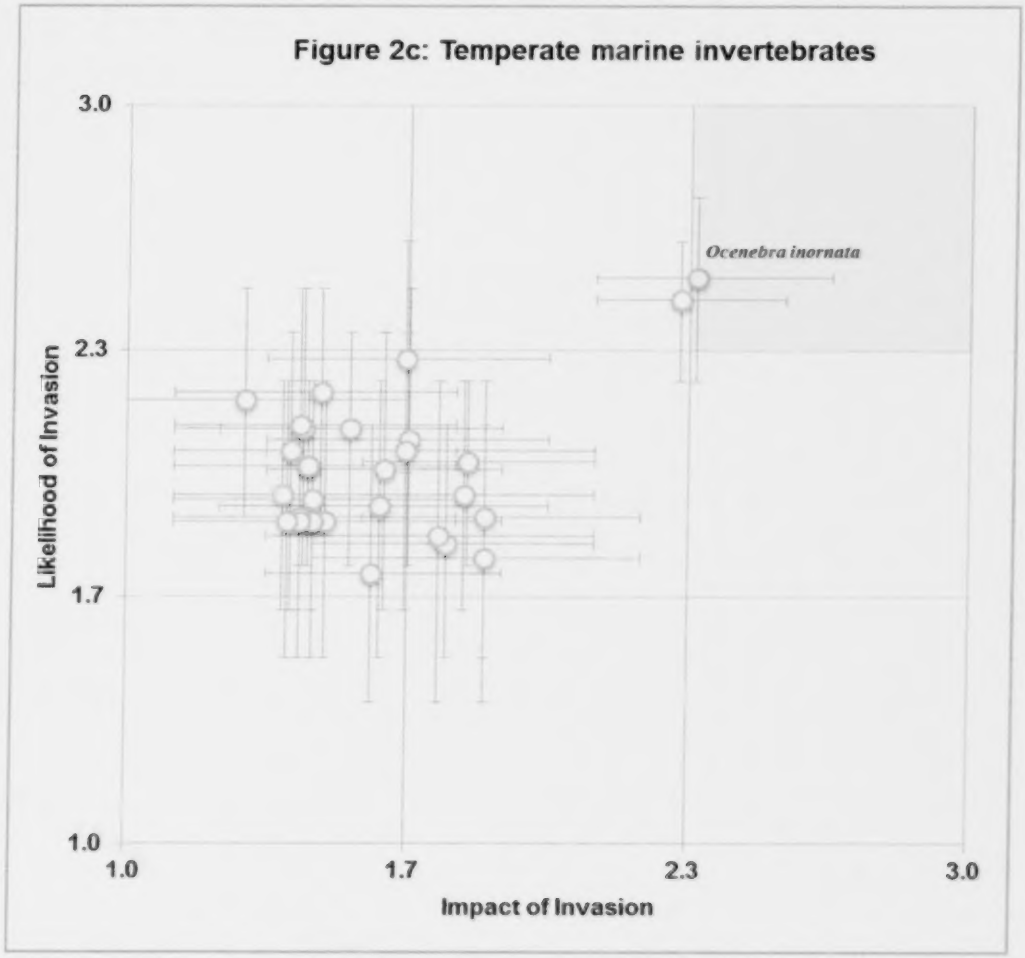


Figure 2 (C): CMIST Scores (adjusted) for 30 temperate marine invertebrates from the subset list of 128 PFR Schedule VIII species. Scores are decomposed to Likelihood of Invasion and Impact of Invasion, and displayed in a heat matrix to identify higher risk species following DFO (2015). Higher risk species are in the upper right shaded corner.

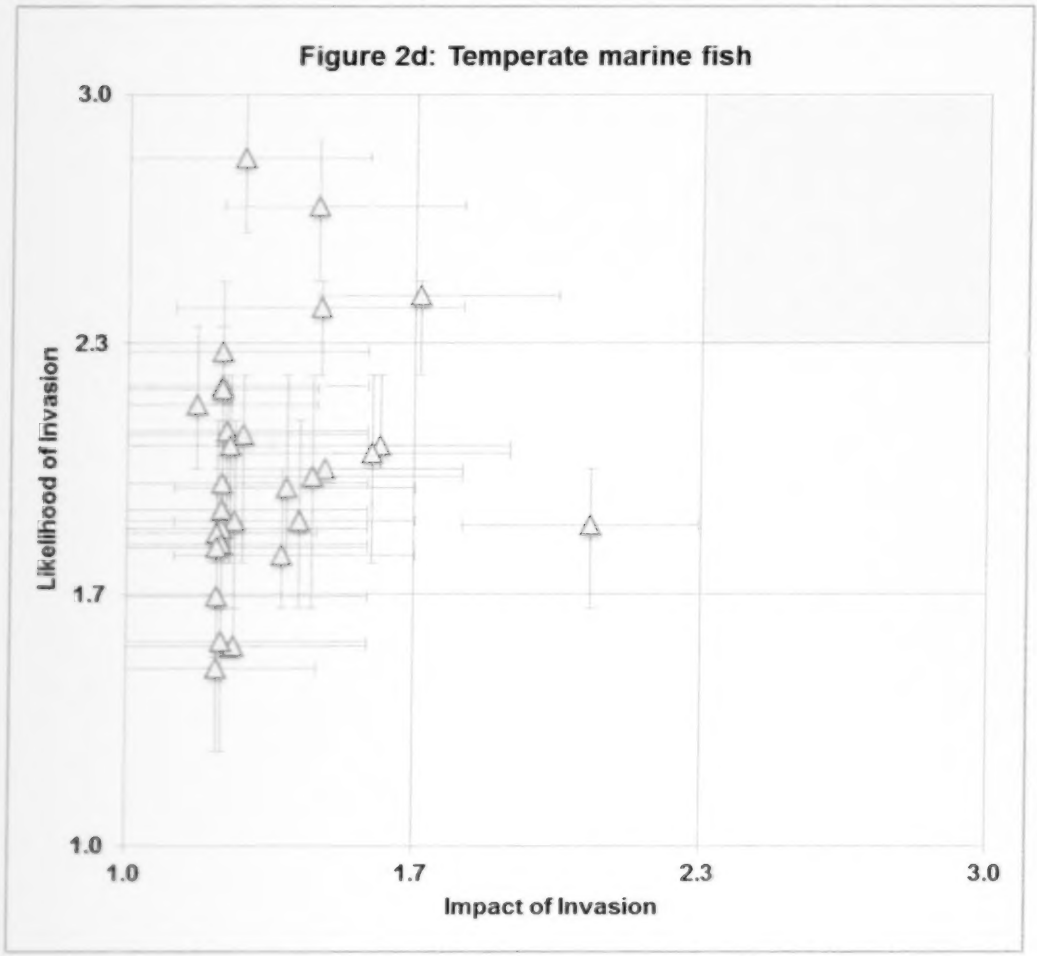


Figure 2 (D): CMIST Scores (adjusted) for 30 temperate marine fish from the subset list of 128 PFR Schedule VIII species. Scores are decomposed to Likelihood of Invasion and Impact of Invasion, and displayed in a heat matrix to identify higher risk species following DFO (2015). Higher risk species are in the upper right shaded corner.

Mandrak et al. (2014) identified freshwater fish species in trade that could pose an invasion risk to Canada. To do so, they created a validation dataset using expert opinion of ecological impacts of species already established in the Laurentian Great Lakes to classify these fishes as low, moderate, or high impact in the Great Lakes. Although the assessment area and methodologies differ from those used here, it does provide an independent measure of ecological impact for comparison purposes. Thus, following the approach used in DFO (2015) we plotted each of the 23 PFR Schedule VIII species that were assessed in both Mandrak et al. (2014) and this SR using CMIST using adjusted Likeiihood of Invasion and adjusted Impact of Invasion scores (Figure 3). Trends were similar among the two methodologies with moderate-higher risk/impact species clustering to the middle-upper right and iower risk/impact ones clustering to the middle-lower left (Figure 3, Table A3).

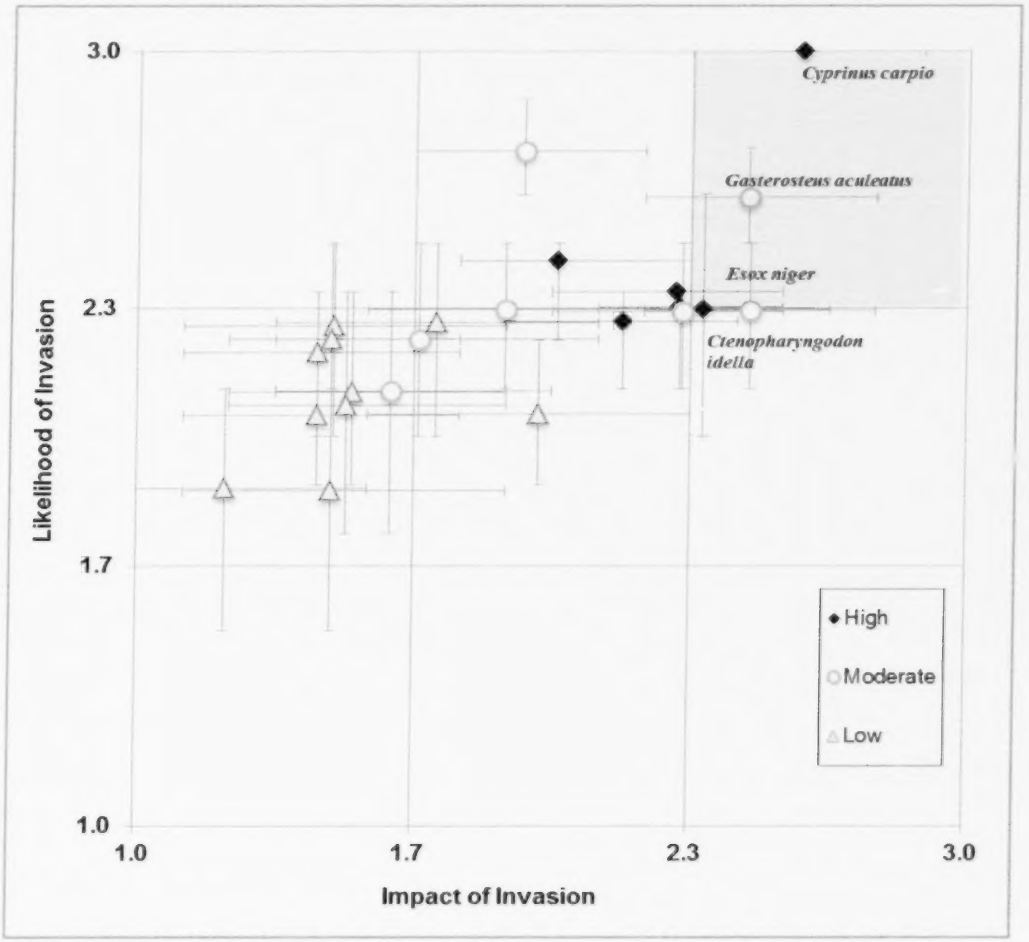


Figure 3: CMIST Scores (adjusted) for 23 PFR Schedule VIII species assessed with CMIST for British Columbia also assessed by Mandrak et al. (2014) decomposed to Likelihood of Invasion and Impact of Invasion displayed in a heat matrix to identify higher risk species following DFO (2015). Higher risk species are in the upper right shaded corner. Ecological impact classification (high, moderate, low) based on Mandrak et al. (2014).

Prioritization of PFR Schedule VIII Species with Climate Match

All PFR Schedule VIII species that have a climate match to British Columbia should be assessed for invasion risk with CMIST. However, this subset is long and depending on resources could take considerable time. Thus, there are additional factors that could be used to help prioritize species assessments for such a long list. For example, species that are prohibited or restricted elsewhere based on invasiveness, especially if in relatively close proximity to British Columbia, could pose a risk to British Columbia. Once climate match was assessed, to help with prioritizing species for the PFR Schedule VIII assessment, a "hit list" was generated based on species that are either restricted or on watch lists in Canada federally, provincially, or in the United States, especially in neighboring jurisdictions (e.g., AIS Regulations in Canada's Fisheries Act, Washington State's WAC 220-12-090 Classification - Nonnative aquatic animal species, etc.). These species were prioritized for assessment with CMIST first,

but the case of Blue Tilapia illustrates the importance of screening all species with a climate match to ensure all potential higher risk species are identified.

Another important consideration is if the species is associated with a known invasion vector. If this information is known (e.g., from import permits) then this would be another factor to consider in prioritization. However, this information often is not known (and was not available for PFR Schedule VIII species) so a simpler approach would be geographic connectivity and proximity. For example, this would prioritize species that have native or other invaded distributions close to British Columbia and then radiate out such that applying this approach would result in assessing species located elsewhere in North America before assessing those with distributions overseas (e.g., Asia, Europe, Africa, South America, Australia). Again, it is important to recall that this is simply an internal prioritization process as all species with a climate match should be assessed.

Additionally, if a species has a known invasion history elsewhere it could be a good prioritization factor (and is a question in CMIST) (e.g., Reichard and Hamilton 1997, Boudouresque and Verlaque 2002). Although this question relies on a relatively robust understanding of invasions elsewhere, which might be better known for terrestrial/agricultural invaders or even freshwater fish than marine invertebrates or relatively new invaders, if available it could allow prioritization of species for the application of CMIST.

Conclusions

CMIST is based on the generalized invasion process and is not taxa or ecosystem-specific. Thus, it was designed to be broadly applicable to multiple taxa and in fact there were no challenges encountered when applying this tool to the suite of taxa listed in the PFR Schedule VIII. Further, when CMIST is applied in a consistent manner within an assessment area, there is no reason to expect the relative risk scores would not be comparable across multiple taxa. This process verified that CMIST can be applied to all taxa listed in the PFR Schedule VIII, including fishes that were not included in initial CMIST tool development or testing.

Given that CMIST was developed and tested for marine invertebrates in a previous CSAS process (DFO 2015; DFO 2016), and that in this process the two oyster drills that were assessed previously for the Strait of Georgia (Drolet et al., 2016) scored similarly, CMIST was deemed suitable for application to the gastropods and crustaceans listed in the PFR Schedule VIII.

There were detailed-level risk assessments completed for some freshwater fishes listed in the PFR Schedule VIII which allowed comparison to CMIST results here. Higher risk species (as identified in detailed-level assessments) like Northern Pike, Largemouth Bass, Smallmouth Bass, Yellow Perch, Walleye, and Pumpkinseed all scored relatively high in this assessment. Further, CMIST results for the Asian Carp species were comparable to detailed-level risk assessments completed for them as well. Also, results of a previous study using expert opinion to assess ecological impacts of freshwater fish in trade within the Great Lakes (Mandrak et al. 2014) were in general agreement with CMIST scores generated here for British Columbia. For both lower risk and moderate-higher risk fish species the CMIST scores were in general agreement with those from Figure 1 in Mandrak et al. (2014). Thus, CMIST was deemed suitable for application to freshwater fishes listed in the PFR Schedule VIII.

No detailed or screening-level risk assessments were available for non-freshwater fish species to compare CMIST results to as there are very few examples of higher risk marine/brackish water fish species. However, there is no reason to suggest CMIST is not suitable for these species. For example, the Red Lionfish, a known high profile invasive piscivore scored

relatively higher with respect to impact of invasion. Further, CMIST was developed and tested for marine invertebrates providing additional indirect evidence for application in comparable environments. Thus, CMIST was deemed suitable for application to non-freshwater fishes listed in the PFR Schedule VIII.

Future Considerations

All temperate PFR Schedule VIII species, fishes and invertebrates, should be assessed for risk of invasiveness using a screening level risk assessment tool. Continued application of CMIST to the PFR Schedule VIII will allow comparisons across taxa listed there. Results could inform future amendments to the AIS Regulations.

The PFR Schedule VIII is relatively constrained with respect to the species it applies to and British Columbia has identified other high risk invasive species in their Provincial Regulations For example, the provincial CAS Regulation applies to Snakeheads (*Channa* spp.) but these are not listed in the PFR Schedule VIII. In fact, a previous detailed risk assessment showed Northern Snakehead (*Channa argus*) was high risk in Canada (Cudmore and Mandrak 2005). There are additional examples of regulated/restricted species in adjacent jurisdictions based on our "hit" list that suggest some may be invasive in British Columbia as well. Higher risk AIS not listed in the PFR Schedule VIII should be screened for invasiveness if risk assessments have not been completed for the assessment area. Application of CMIST to these non-PFR Schedule VIII species will allow comparisons with those in the PFR Schedule VIII assessed with CMIST.

Assessors using CMIST document their rationale and support for each question scored and their level of certainty. This ancillary information is extremely valuable for future ecological or socio-economic risk assessments as it provides additional context and information, and it allows information on risk to be updated for individual species as needed (see comments in Table 1 in DFO 2015). Thus, answers to CMIST questions indicating rationale for scoring and certainty should be deposited in a searchable, accessible database for supporting information.

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Appendices

Table A1: Pacific Fisheries Regulation Schedule VIII.

Schedule VIII (*Section 5*), Prohibited Import Live Fish

Item	Column I Common Name of Species	Column II Scientific Name of Species
1	Bass, Blue Gill sunfish	*Acantharchus*, *Ambloplites*, *Centrarchus*, *Enneacanthus*, *Lepomis*, *Micropterus*, *Morone*, *Perca*, *Percina*, *Pomoxis* and *Stizostedium*
2	Blackfish (Sacramento)	*Orthodon*
3	Bowfin	*Amia calva*
4	Buffalo fish	*Ictiobus*
5	Carp	*Catla*, *Cirrhina*, *Ctenopharyngodon*, *Cyprinus*, *Hypothal michthys*, *Labeo* and *Mylopharyngodon*
6	Catfish	*Clarias*, *Ictalurus* and *Noturus*
7	Drum (Sheepshead)	*Aplodinotus*
8	Eel	*Anguilla*
9	Minnow (Fathead)	*Pimephales*
10	Gars	*Lepisosteus*
11	Lamprey	*Ichthyomyzan*, *Lampetra* and *Petromyzon*
12	Pike	*Esox*
13	Quilback and Carpsucker	*Carpiodes*
14	Roach	*Leuciscus*
15	Rudd	*Scardinius*
16	Shad and Alewife	*Alosa* and *Dorosoma*
17	Stickleback	*Apeltes*, *Culaea* (*Eucalia*), *Gasteroteus steus* and *Pungitius*
18	Sucker	*Catostomus*, *Cycleptus*, *Erimyzon*, *Hypenelium*, *Minytrema* and *Moxostoma*
19	Tilapia	*Tilapia*
20	Moon snail	*Polinices*
21	Oyster crab	*Pinnotheres*
22	Oyster drill	*Thais*, *Ocenebra* and *Urosalpinx*
23	Rock lobster	*Jasus*

Table A2: CMIST Scores (adjusted) and Likelihood of Invasion (adjusted) and Impact of Invasion (adjusted) for 128 PFR Schedule VIII species (38 temperate freshwater fish, 30 sub-tropical/tropical freshwater fish, 30 temperate marine invertebrates, 30 temperate marine fish). Taxa are either Fish (F) or Invertebrates (I); Climate match to British Columbia (C) or No Climate match to British Columbia (NC); Habitat is Freshwater (FW) or Marine (M); "Hit List" (H) applies to species on regulatory or watch lists or not (NH); Status represents either current valid nomenclature in agreement with the PFR Schedule VIII (P) or nomenclature has changed and species is recognized in an Alternate genus (A).

Common Name	Latin Name	Taxa	Climate Match	Habitat	"Hit List"	Status	Adj. Likelihood	Adj. Impact	Adj. CMIST Score
Common carp / Koi	*Cyprinus carpio*	F	C	FW	H	P	3.00	2.60	7.81
Northern pike	*Esox lucius*	F	C	FW	H	P	2.79	2.68	7.48
Walleye	*Sander vitreus*	F	C	FW	H	P	2.86	2.59	7.41
Largemouth bass	*Micropterus salmoides*	F	C	FW	H	P	2.85	2.57	7.33
Smallmouth bass	*Micropterus dolomieu*	F	C	FW	H	P	2.80	2.57	7.19
Brown bullhead	*Ameiurus nebulosus*	F	C	FW	H	A	2.96	2.36	6.99
Yellow perch	*Perca flavescens*	F	C	FW	H	P	2.88	2.42	6.96
Roach	*Rutilus rutilus*	F	C	FW	H	A	2.46	2.75	6.77
Silver carp	*Hypophthalmichthys molitrix*	F	C	FW	H	P	2.45	2.45	6.00
Pumpkinseed	*Lepomis gibbosus*	F	C	FW	H	P	2.45	2.44	5.97
Japanese oyster drill	*Ocenebra inornata*	I	C	M	H	P	2.53	2.35	5.96
Black carp	*Mylopharyngodon piceus*	F	C	FW	H	P	2.34	2.49	5.82
Atlantic oyster drill	*Urosalpinx cinerea*	I	C	M	H	P	2.47	2.31	5.71
Blue tilapia	*Oreochromis aureus*	F	C	FW	NH	A	2.43	2.30	5.58
Northern pikeminnow	*Ptychocheilus oregonensis*	F	C	FW	NH	A	2.79	2.00	5.58
Grass carp	*Ctenopharyngodon idella*	F	C	FW	H	P	2.33	2.37	5.51
Bighead carp	*Hypophthalmichthys nobilis*	F	C	FW	H	P	2.29	2.38	5.45
White crappie	*Pomoxis annularis*	F	C	FW	NH	P	2.25	2.26	5.09
Sauger	*Sander canadensis*	F	C	FW	NH	P	2.43	1.91	4.63
Western river lamprey	*Lampetra ayresii*	F	C	FW	NH	P	2.59	1.77	4.59
Gudgeon	*Gobio gobio*	F	C	FW	H	A	2.56	1.74	4.46
Brook stickleback	*Culaea inconstans*	F	C	FW	H	P	2.57	1.64	4.21
Atlantic herring	*Clupea harengus*	F	C	M	H	A	2.46	1.68	4.12
River lamprey	*Lampetra fluviatilis*	F	C	FW	H	P	2.31	1.73	4.00
Yellow bass	*Morone mississippiensis*	F	C	FW	H	P	2.29	1.72	3.95
Pacific sardine	*Sardinops sagax*	F	C	M	H	A	2.70	1.44	3.88
Red lionfish	*Pterois volitans*	F	C	M	H	A	1.85	2.08	3.86
Redfin pickerel	*Esox americanus*	F	C	FW	H	P	2.30	1.68	3.86
Northern moon snail	*Euspira heros*	I	C	M	H	A	2.31	1.66	3.82
Cape rock lobster	*Jasus lalandii*	I	C	M	H	P	2.03	1.81	3.68
Pilotfish	*Naucrates ductor*	F	C	M	NH	A	2.83	1.27	3.59
Golden redfish	*Sebastes norvegicus*	F	C	M	NH	A	2.43	1.45	3.51
U. circumtexta (a drill)	*Urosalpinx circumtexta*	I	C	M	H	P	1.88	1.85	3.49
European sting winkle	*Ocenebra erinaceus*	I	C	M	H	P	1.94	1.80	3.48
Pale northern moonsnail	*Euspira trisenata*	I	C	M	H	A	2.09	1.67	3.48
Immaculate moonsnail	*Polinices immaculatus*	I	C	M	H	P	2.06	1.66	3.43
Bluefish	*Pomatomus saltatrix*	F	C	M	NH	A	2.06	1.59	3.27
U. haneti (a drill)	*Urosalpinx haneti*	I	C	M	H	P	1.77	1.85	3.27
Sampa	*Heterobranchus longifilis*	F	NC	FW	H	A	1.90	1.71	3.25
Southern rock lobster	*Jasus edwardsii*	I	C	M	H	P	2.12	1.53	3.23
P. pisum (a pea crab)	*Pinnotheres pisum*	I	C	M	H	P	2.22	1.46	3.23
Atlantic dogwinkle	*Nucella lapillus*	I	C	M	H	A	2.01	1.61	3.22
Blackspotted stickleback	*Gasterosteus wheatlandi*	F	C	M	H	P	2.04	1.57	3.20
Southern oyster drill	*Stramonita canaliculata*	I	C	M	H	A	1.81	1.76	3.19

Common Name	Latin Name	Taxa	Climate Match	Habitat	"Hit List"	Status	Adj. Likelihood	Adj. Impact	Adj. CMIST Score
O. brevirobusta (a drill)	*Ocenebra brevirobusta*	I	C	M	H	P	1.83	1.74	3.19
Trahira	*Hoplias malabaricus*	F	NC	FW	NH	A	1.90	1.66	3.16
O. lumaria (a drill)	*Ocenebra lumaria*	I	C	M	H	P	1.91	1.60	3.05
Catla	*Catla catla*	F	NC	FW	NH	P	1.79	1.70	3.03
Squatter pea crab	*Tumidotheres maculatus*	I	C	M	H	A	2.13	1.41	3.00
Oyster pea crab	*Zaops ostreus*	I	C	M	H	A	2.12	1.42	3.00
Indian mottled eel	*Anguilla bengalensis*	F	NC	FW	NH	P	1.81	1.64	2.96
Blunt-toothed African catfish	*Clarias ngamensis*	F	NC	FW	H	P	1.86	1.58	2.95
Largescale silver carp	*Hypophthalmichthys harmandi*	F	NC	FW	H	P	2.13	1.38	2.93
Cobia	*Rachycentron canadum*	F	C	M	H	A	2.00	1.46	2.92
Tropical gar	*Atractosteus tropicus*	F	NC	FW	H	A	1.79	1.62	2.90
Juan Fernandez rock lobster	*Jasus frontalis*	I	C	M	H	P	2.02	1.43	2.89
Green rock lobster	*Sagmariasus verreauxi*	I	C	M	H	A	2.02	1.43	2.88
Chapala catfish	*Ictalurus ochoterenai*	F	NC	FW	H	P	1.82	1.58	2.86
P. nanus (a tiny moonsnail)	*Pseudopolinices nanus*	I	C	M	H	A	2.06	1.39	2.85
Striped killifish	*Fundulus majalis*	F	C	M	H	A	1.98	1.43	2.84
N. pinnotheres (a pea crab)	*Nepinnotheres pinnotheres*	I	C	M	H	A	2.20	1.28	2.82
Rudderfish	*Centrolophus niger*	F	C	M	NH	A	2.31	1.22	2.82
Balsas catfish	*Ictalurus balsanus*	F	NC	FW	H	P	1.81	1.55	2.80
J. caveorus (a rock lobster)	*Jasus caveorum*	I	C	M	H	P	1.93	1.44	2.79
Alaskan brook lamprey	*Lethenteron alaskense*	F	C	FW	NH	A	2.18	1.27	2.76
P. gordoni (a pea crab)	*Pinnotheres gordoni*	I	C	M	H	P	1.87	1.47	2.74
R. luteostoma (a drill)	*Reishia luteostoma*	I	C	M	H	A	1.73	1.58	2.74
Headwater catfish	*Ictalurus lupus*	F	NC	FW	H	P	1.82	1.51	2.74
Yaqui catfish	*Ictalurus pricei*	F	NC	FW	H	P	1.82	1.50	2.74
Flying gurnard	*Dactylopterus volitans*	F	C	M	NH	A	2.22	1.22	2.71
P. pholadis (a pea crab)	*Pinnotheres pholadis*	I	C	M	H	P	1.87	1.44	2.70
Atlantic saury	*Scomberesox saurus*	F	C	M	NH	A	2.21	1.22	2.69
Cape jagged lobster	*Projasus parkeri*	I	C	M	H	A	1.87	1.44	2.69
American conger	*Conger oceanicus*	F	C	M	NH	A	1.95	1.37	2.67
Boa dragonfish	*Stomias boa boa*	F	C	M	NH	A	2.09	1.27	2.66
St Paul rock lobster	*Jasus paulensis*	I	C	M	H	P	1.94	1.37	2.65
C. uelensis (airbreathing catfish)	*Clariallabes uelensis*	F	NC	FW	H	A	1.69	1.57	2.65
R. clavigera (a drill)	*Reishia clavigera*	I	C	M	H	A	1.88	1.41	2.65
A. sinensis (a pea crab)	*Arcotheres sinensis*	I	C	M	H	A	1.87	1.41	2.63
Shoal bass	*Micropterus cataractae*	F	NC	FW	NH	P	1.65	1.59	2.63
Southeastern blue sucker	*Cycleptus meridionalis*	F	NC	FW	NH	P	2.08	1.26	2.62
Convict grouper	*Hyporthodus septemfasciatus*	F	C	M	H	A	1.86	1.40	2.61
Lerma catfish	*Ictalurus dugesii*	F	NC	FW	H	P	1.82	1.43	2.61
P. cyclinus (a pea crab)	*Pinnotheres cyclinus*	I	C	M	H	P	1.87	1.38	2.58
Atlantic croaker	*Micropogonias undulatus*	F	C	M	NH	A	2.10	1.23	2.57
Spot croaker	*Leiostomus xanthurus*	F	C	M	NH	A	2.06	1.24	2.56
Suwannee bass	*Micropterus notius*	F	NC	FW	NH	P	1.71	1.49	2.54
Hickory shad	*Alosa mediocris*	F	C	FW	NH	P	2.02	1.26	2.54
Spottail chub	*Algansea tincella*	F	NC	FW	NH	A	1.81	1.39	2.52
Pigfish	*Orthopristis chrysoptera*	F	C	M	NH	A	2.17	1.16	2.52
Gray redhorse	*Moxostoma congestum*	F	NC	FW	NH	P	1.86	1.35	2.51
Flat bullhead	*Ameiurus platycephalus*	F	C	FW	H	A	1.83	1.36	2.50
Pacific gizzard shad	*Dorosoma smithi*	F	NC	FW	NH	P	1.66	1.48	2.46
Chucky madtom	*Noturus crypticus*	F	NC	FW	H	P	1.72	1.42	2.45
Bata	*Labeo bata*	F	NC	FW	NH	P	1.73	1.40	2.43
Elegant madtom	*Noturus elegans*	F	C	FW	H	P	1.67	1.45	2.41
Great barracuda	*Sphyraena barracuda*	F	C	M	NH	A	1.77	1.36	2.40

Common Name	Latin Name	Taxa	Climate Match	Habitat	"Hit List"	Status	Adj. Likelihood	Adj. Impact	Adj. CMIST Score
Southern kingcroaker	*Menticirrhus americanus*	F	C	M	NH	A	1.96	1.22	2.39
Spotted bullhead	*Ameiurus serracanthus*	F	NC	FW	H	A	1.60	1.48	2.38
Rock sea bass	*Centropristis philadelphica*	F	C	M	NH	A	1.86	1.25	2.33
Saddled madtom	*Noturus fasciatus*	F	NC	FW	H	P	1.71	1.35	2.31
Ballyhoo halfbeak	*Hemiramphus brasiliensis*	F	C	M	NH	A	1.89	1.22	2.31
Piebald madtom	*Noturus gladiator*	F	NC	FW	H	P	1.71	1.35	2.30
Mountain brook lamprey	*Ichthyomyzon greeleyi*	F	C	FW	NH	P	1.89	1.21	2.29
Pacific brook lamprey	*Lampetra pacifica*	F	C	FW	NH	P	1.84	1.25	2.29
Bullhead minnow	*Pimephales vigilax*	F	C	FW	NH	P	1.83	1.25	2.29
Bermuda sea chub	*Kyphosus sectatrix*	F	C	M	NH	A	1.84	1.22	2.25
Dollar sunfish	*Lepomis marginatus*	F	NC	FW	NH	P	1.79	1.24	2.22
Broad-striped anchovy	*Anchoa hepsetus*	F	C	M	NH	A	1.83	1.21	2.22
Snail bullhead	*Ameiurus brunneus*	F	C	FW	H	A	1.61	1.38	2.21
Ozark madtom	*Noturus albater*	F	C	FW	H	P	1.56	1.42	2.20
Atlantic bumper	*Chloroscombrus chrysurus*	F	C	M	NH	A	1.80	1.22	2.20
Stymphalia chub	*Squalius moreoticus*	F	NC	FW	NH	A	1.63	1.34	2.18
Sand perch	*Diplectrum formosum*	F	C	M	NH	A	1.79	1.21	2.17
Fleshylip buffalo	*Ictiobus labiosus*	F	NC	FW	NH	P	1.54	1.37	2.12
Lake chubsucker	*Erimyzon sucetta*	F	C	FW	H	P	1.56	1.34	2.09
Creole perch	*Percichthys trucha*	F	NC	FW	NH	A	1.61	1.29	2.07
Bigeye cichlid	*Acaronia nassa*	F	NC	FW	NH	A	1.59	1.27	2.02
Squirrelfish	*Holocentrus adscensionis*	F	C	M	NH	A	1.66	1.21	2.01
Bonefish	*Albula vulpes*	F	C	M	NH	A	1.53	1.25	1.91
Amber darter	*Percina antesella*	F	C	FW	NH	P	1.48	1.27	1.88
Schoolmaster snapper	*Lutjanus apodus*	F	C	M	NH	A	1.54	1.22	1.88
Blotchside darter	*Percina burtoni*	F	C	FW	NH	P	1.49	1.25	1.86
Tangerine darter	*Percina aurantiaca*	F	C	FW	NH	P	1.48	1.25	1.86
Western Atlantic seabream	*Archosargus rhomboidalis*	F	C	M	NH	A	1.47	1.21	1.78
Blackfin sucker	*Thoburnia atripinnis*	F	C	FW	NH	A	1.40	1.26	1.77
Sailfin shiner	*Pteronotropis hypselopterus*	F	C	FW	NH	A	1.40	1.25	1.75
Lake Victoria deepwater catfish	*Xenoclarias eupogon*	F	NC	FW	H	A	1.48	1.05	1.56

Table A3: CMIST Scores (adjusted) and Likelihood of Invasion (adjusted) and Impact of Invasion (adjusted) for 23 PFR Schedule VIII species in common with Mandrak et al. (2014). Taxa are Fish (F); Climate match to British Columbia (C); Habitat is Freshwater (FW); "Hit List" (H) applies to species on regulatory or watch lists or not (NH); Status represents either current valid nomenclature in agreement with PFR Schedule VIII (P) or nomenclature has changed and species is recognized in an Alternate genus (A); and Risk rating provided by expert opinion for the Great Lakes as High (H), Moderate (M), or Low (L).

Common Name	Latin Name	Taxa	Climate Match	Habitat	"Hit List"	Status	Adj. Likelihood	Adj. Impact	Adj. CMIST Score (BC)	Rating by experts (GL)
Common carp / Koi	*Cyprinus carpio*	F	C	FW	H	P	3.00	2.60	7.81	H
Three-spined stickleback	*Gasterosteus aculeatus*	F	C	FW	H	P	2.62	2.47	6.47	M
Chain pickerel	*Esox niger*	F	C	FW	H	P	2.33	2.48	5.76	M
Grass carp	*Ctenopharyngodon idella*	F	C	FW	H	P	2.33	2.37	5.51	H
Sea lamprey	*Petromyzon marinus*	F	C	FW	H	P	2.38	2.30	5.46	H
Alewife	*Alosa pseudoharengus*	F	C	FW	H	P	2.33	2.31	5.39	H
Rudd	*Scardinius erythrophthalmus*	F	C	FW	H	P	2.32	2.31	5.38	M
Goldfish	*Carassius auratus*	F	C	FW	H	A	2.74	1.93	5.29	M
White perch	*Morone americana*	F	C	FW	H	P	2.30	2.17	4.99	H
Ruffe	*Gymnocephalus cernua*	F	C	FW	H	A	2.46	2.01	4.95	H
Red shiner	*Cyprinella lutrensis*	F	C	FW	H	A	2.33	1.89	4.40	M
Fourspine stickleback	*Apeltes quadracus*	F	C	FW	H	P	2.06	1.97	4.05	L
Yellow bass	*Morone mississippiensis*	F	C	FW	H	P	2.29	1.72	3.95	L
Freshwater drum	*Aplodinotus grunniens*	F	C	FW	H	P	2.25	1.68	3.78	M
Redear sunfish	*Lepomis microlophus*	F	C	FW	NH	P	2.12	1.61	3.41	M
Black buffalo	*Ictiobus niger*	F	C	FW	NH	P	2.29	1.47	3.37	L
Smallmouth buffalo	*Ictiobus bubalus*	F	C	FW	NH	P	2.25	1.47	3.31	L
Blueback herring	*Alosa aestivalis*	F	C	FW	NH	P	2.12	1.52	3.21	L
Bigmouth buffalo	*Ictiobus cyprinellus*	F	C	FW	NH	P	2.22	1.44	3.18	L
Orangespotted sunfish	*Lepomis humilis*	F	C	FW	H	P	2.08	1.51	3.13	L
River carpsucker	*Carpiodes carpio*	F	C	FW	NH	P	2.05	1.44	2.95	L
Margined madtom	*Noturus insignis*	F	C	FW	H	P	1.86	1.47	2.73	L
Bluespotted sunfish	*Enneacanthus gloriosus*	F	C	FW	NH	P	1.87	1.21	2.26	L

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